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XIII.

BRIEF CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD COLLEGE.

BY JOHN TROWBRIDGE.

No. IV.—ON THE EFFECT OF THIN PLATES OF IRON USED AS ARMATURES TO ELECTRO-MAGNETS.

Presented, Feb. 9, 1876.

In a paper presented to the Academy, April 13, 1875, I showed that the application of armatures to two strait electro-magnets, which formed the primary circuit of a Ruhmkorf coil, more than doubled the strength of the induction current produced by breaking the primary circuit. When, however, the circuit of the secondary coil was not closed, and a spark was allowed to jump across the interval between its poles, the striking distance of the spark, and its power to charge a condenser, did not seem to be notably increased by the applications of armatures to the electro-magnets of the primary circuit. My experiments, at that time, were made with solid iron cores; and I now resume these experiments with bundles of fine iron wires in place of the solid iron cores. The mechanical difficulty of making the ends of the bundles of fine wires constituting the cores plane surfaces was overcome by dipping them in melted solder, and then filing the surfaces. In this way, I had no difficulty in applying the armatures so that they should lie upon a plane surface.

The resistance of each of the two induction coils covering the two strait electro-magnets was 6000 ohms, and that of each of the strait electro-magnets .34 of an ohm. The diameter of the bundles of fine iron wires constituting the cores was 5 c.m., and the length of the electro-magnets was 28 c.m. Condensers of various sizes were placed in the primary circuit: the results given in this paper were obtained by the use of a condenser of about one Farad. The method of experimenting was to charge a condenser of $\frac{1}{3}$ of a Farad by means of a spark one millimetre in length, and then to discharge this condenser through a galvanometer. If we express the quantity of electricity

received by the condenser by Q , the electro-motive force and the capacity of the condenser by E and C , we have $Q = EC$. We also have $Q = \frac{2nt}{\pi} \sin \frac{1}{2} \varphi$, where n is the reduction factor of the galvanometer, t the time of vibration of the magnet, and φ the arc through which it swings under the effect of the charge. Knowing the reduction factor of my galvanometer, I had thus the means of reducing my results to absolute measure. But I speedily found that the relative results obtained by the proportions

$$Q : Q' = \sin \frac{1}{2} \varphi : \sin \frac{1}{2} \varphi' = E : E'$$

would present the points of this investigation in a manner as valuable as if the results had been reduced to absolute magnetic measure.

My first experiments were made with solid armatures.

TABLE I.

Without armatures.		With armatures.	
	80		90
	70		80
	90		100
	60		70
	70		85
	80		90
	—		—
Mean	75		86

In this table, the numbers are the deflections of the reflecting galvanometer expressed in millimetres. In this case, the gain by the use of the armatures was trifling, being only about 14 per cent. These results were obtained by charging the condenser of $\frac{1}{3}$ of a Farad, by sparks one millimetre in length.

On a closed secondary circuit, however, a gain of one hundred per cent was clearly shown in the strength of the induced current produced by breaking the primary circuit. The question of how to make this great increase in the strength of the induced current by the employment of armatures manifest in the spark became an interesting one. It seemed at first as if the application of armatures, by maintaining the temporary magnetization of the iron cores, would be detrimental rather than otherwise.

I next tried the effect of bundles of thin iron plates, which were

placed as armatures upon both poles of the electro-magnets, thus making a magnet of a horse-shoe form. On charging the condenser, I found a very great increase in quantity, which was manifested by the swing of the galvanometer needle, the indications being entirely off the scale. Table II. shows the results obtained by the use of iron plates $\frac{1}{32}$ of an inch in thickness, twenty in number, constituting each armature.

TABLE II.

Without plates.	With plates.
80	400
70	380
90	370
60	400
70	370
80	400
Mean 75	Mean 386.6

Here a gain of four hundred per cent was manifested by the use of the thin plates.

The next step was to ascertain how many plates were necessary to obtain the maximum effect. The difficulty of obtaining plates of the same homogeneity made it impossible to obtain smooth curves. To this difficulty was added that of breaking the primary circuit in a regular manner.

If the results of Table III. are plotted, it will be seen that the increase within small limits is very nearly proportional to the number of thin plates, which were $\frac{1}{32}$ of an inch in thickness.

TABLE III.

No. of plates.	Deflections of galv.	No. of plates.	Deflections of galv.
1	11	6	15
2	12	7	15.5
3	13	8	16
4	13	9	18
5	14	10	18.5

On increasing the number of plates, a point was reached where there was no additional effect. The best result was obtained where the mass of the armatures was approximately equal to that of the cores of the electro-magnets. Plates of $\frac{1}{32}$ of an inch in thickness were also used; but no advantage resulted in their employment, over those of $\frac{1}{64}$ of an inch. It would seem that the thin plates followed the same law as that of the bundle of fine iron wires which constitute the cores of induction coils of the present day, and that only a moderate degree of discontinuity in the mass of iron submitted to magnetic influence is necessary to prevent the formation of currents of induction which prolong the magnetism of the cores, and prevent the quick demagnetization necessary to produce intense currents of induction. The effect of insulating the thin plates with thin dielectrics, like paper, was also tried with no gain in effect. There appeared to be a slight gain by placing the plates edgewise on the poles of the electro-magnets, instead of allowing them to repose on their flat sides. This was doubtless due to better contact of the metallic surfaces.

Since the above results proved conclusively a very great gain in quantity and electro-motive force by the application of thin plates as armatures, I next measured the striking distance of the spark. Table IV. gives the results which are the mean of many trials.

TABLE IV.

Without armatures.	With armatures.
15 <i>c.m.</i>	32 <i>c.m.</i>
14 "	30 "
15 "	32 "
—	—
Mean 14.6	31.3

A curious fact came up in this connection. The lengthening of the spark was not shown when the spark leaped directly between the poles of the induction coil. The increase in quantity and electro-motive force was only made manifest to the eye by the employment of condensers in the secondary circuit. The results in Table IV. were obtained by the employment of a Leyden jar of large capacity. The increase in the quantity and electro-motive force was not only shown by the increased length of the spark, but also by its increase in volume and its loud snap. The spark consisted of a thick central bolt, surrounded

by curious thin detached sparks. An attempt was made to measure the increase of light in Geissler tubes by Vierodt's photometric apparatus, but it was found too inexact for this purpose, if, indeed, there was any increase of light, which certainly remains to be proved. I know of no results which bear upon the relation of the increase of light to the increase of electro-motive force of the induction spark.

Without condensers in the secondary circuit, however, the increased electro-motive force of the spark was shown by its greater constancy in leaping over a given resistance of air.

The results of this investigation can be thus summed up : —

1. The application of thin plates of iron as armatures to two strait electro-magnets increases between four and five times the strength of the spark produced by the surrounding secondary coils.
2. The length of the spark is doubled, which is only shown by the use of a condenser in the secondary circuit.
3. The results show that it would be more economical to construct induction coils consisting of two strait electro-magnets constituting the primary circuit, and two fine coils constituting the secondary circuit, with the use of thin plates of iron as armatures to the electro-magnets, than to distribute the same amount of wire on one strait electro-magnet, as in the common form of Ruhmkorf coil.

NO. V. — ON THE SO-CALLED ETHERIC FORCE.

ARTICLES have appeared in various newspapers during the past few weeks, calling the attention of the public to the evidences of a new force discovered by Mr. Edison, of Newark, N.J., which he has termed the Etheric Force. The New York "Tribune" of December 9th contains a letter from Dr. G. M. Beard, which details some experiments which he has tried ; and in the same letter Dr. Beard invites the attention of scientific men to the alleged new phenomena.

Evidence of the force is obtained in the following manner : A bar of cadmium or other metal — cadmium having the preference — is placed upon the poles of a strong horse-shoe electro-magnet, in the same manner that a soft iron armature is usually placed ; an insulated wire is connected with the bar of cadmium ; and when the circuit in which the electro-magnet is placed is rapidly interrupted, either by a key or a vibrating armature, sparks appear at the end of the wire connected with the bar of cadmium. It is claimed that the kind of electricity thus evolved does not answer to the usual tests of static

electricity; that there is no evidence of any polarity; that the force passes through ordinary insulators better than electricity of high tension; that no physiological effects are manifested when the discharge is received by the human body, and that it is impossible to charge a Leyden jar or to affect a sensitive electrometer or mirror galvanometer by this force. The spark, it is claimed, differs from that of ordinary electricity of high tension, in that it requires contact of the end of the wire conducting it with a metal or carbon point presented to it. The best sparks were obtained by rubbing a fine iron wire against a rusty file or stove-pipe. Dr. Beard found that a galvanoscopic frog gave no evidence of the existence of the force, although a spark was received after the passage of the force through the frog. Mr. Edison passed the force through iodized paper for three hours, and no effect was produced. He also took the wire connected with the apparatus out of doors, ran it along the ground and in a ditch on a rainy night, and brought it upstairs several rods from the battery, and the spark was seen by himself and Dr. Beard, at the terminal of the carbon point connected with the wire.

The apparatus which I used to produce the phenomenon was a strong electro-magnet, the limbs of which were six inches long, and were covered with large bobbins of coarse wire, having a resistance each of .70 of an ohm. Bars of iron, steel, and brass, were used as armatures to evolve the force; a copper wire was connected with the bar of metal at various places, sometimes at the end and sometimes in the middle; and the end of this wire was tested by one of Sir William Thomson's quadrant electrometers, by his most delicate mirror galvanometer, and by the carbon points advised by Dr. Beard in his letter which we have referred to at the opening of this article.

The electrometer immediately showed a slight tension on the surface of the bar of metal, which constituted the armature of the electro-magnet. By the method of multiplication, the swing of the needle was increased, so as to give unmistakable indications of polarity; the directions of the indication being in opposite directions at making and breaking the circuit of the electro-magnet.

It was evident that the want of polarity noticed by Mr. Edison was due to the rapid alternating nature of the induction currents produced in the bar of cadmium. That this so-called etheric force was nothing but a phenomenon of induction seemed evident at first sight; but one would hardly have predicted that currents of sufficient intensity could have been created in this way to produce a spark. The phenomenon possesses, however, considerable interest, which seems to have been

overlooked by those who have given explanations of the phenomenon based upon the ordinary laws of induction. Faraday early showed that, if a copper disc be rotated between the poles of a strong electro-magnet, currents of considerable strength could be drawn from it by connecting one end of a wire with the axis of the disc, and the other with its periphery. It has never been shown, to the writer's knowledge, that by suddenly making and breaking the circuit of the electro-magnet a degree of static induction could be produced in a copper disc sufficient to produce a spark. It will be readily seen that making and breaking the circuit of the electro-magnet is equivalent to cutting the lines of force of the magnetic field by quick rotation; and therefore the phenomenon possesses an interest, because it supplies a break in the literature of the subject.

NO. VI.—ON A NEW FORM OF MIRROR GALVANOMETER.

THE want of graduated circles for galvanometers is often seriously felt in Physical Laboratories. The method of reading the deflections of the needle by the reflection of a spot of light from a minute concave mirror over a scale, or by the reflection of a scale in a plane mirror attached to the swinging magnet, are methods of great delicacy.

In certain cases, it is difficult to obtain suitable mirrors. I present the following method of reading the deflections of a galvanometer needle, without the aid of minute mirrors either plane or concave, which are usually attached to the magnet. In this method, the mirror is stationary, while the magnet moves. I have applied the method to Helmholtz's modification of Gangain's galvanometer. In the line passing through the pivot or line of suspension of the needle, not necessarily above the centre of the needle, but somewhere in a line passing through its centre, and perpendicular to its length, an ordinary plane mirror is placed. A piece of looking-glass will answer. The silvering of the upper half of the strip of looking-glass is removed, and a fine scale is etched upon it; or for rough purposes a paper millimetre scale is pasted upon the unsilvered portion.

It will be readily seen that for small deflections with a magnet provided with the ordinary long aluminum pointers, tipped at the ends with a small vertical point, if the eye be placed so that the vertical point and its image in the mirror are in the same line that the projection of the arc of the circle of which the needle with its pointers constitutes the diameter, can be read along the scale placed upon the mirror.

For small angles, this projection is very nearly equal to the arc itself, for it is the sine of it; and if R is half the length of the needle with its pointer, and M the projection on the mirror, then the angle $\alpha = \sin \frac{M}{R}$ or $\sin \alpha = \frac{M}{R}$.

This method obviates the difficulty of placing a plane mirror upon a magnet, so that it shall be perpendicular to it, and also in a vertical position in order that the image of a scale reflected from it can be seen in a telescope, which is often a troublesome adjustment. It is true that long pointers are needed, in order to magnify the indications of the needle; but a telescope pointed with a micrometer can be used, which, after focusing on the vertical point at the end of the aluminum pointer, one can focus on the deflection, and then read the fractions of a division with extreme accuracy. In this case, very long pointers are not necessary. The placing of the mirror perpendicular to the magnet is an adjustment very easily made, for the pointer should coincide with its image at the centre of suspension. A table of natural tangents is therefore not necessary with this form of galvanometer.